MODIS DATA STUDY
TEAM PRESENTATION

May 4, 1990

AGENDA

1. Comparison of Stare Mode Coverage at 40^{o} and 50^{o} Tilts (Riggs, Gregg)
2. Ocean Processing Estimate Comparisons (Gregg)
3. MODIS Long-Term Archive Storage Requirements (Ardanuy)
4. Land Storage Requirements (Riggs, Schols)
5. Ocean Storage Requirements (Gregg)
6. Atmosphere Storage Requirements (Hoyt, Andrews)
6. Level-3 Storage Requirements (Andrews, Schols)

Comparison of Stare Mode Coverage at 40° and 50° Tilts

Simulations of MODIS-T in stare mode tilts of 40° and 50° were run to determine the extent of coverage at each tilt, the difference in extent of coverage, and also determine regions over which data for a bidirectional reflectance distribution function (BRDF) may be acquired. Extent of coverage was determined from simulations of MODIS-T run at tilts of 40°, and 50° for a 16 day (233 orbits) repeat period. Predicted coverage at both tilts and the difference between them is shown in Figure 1.

Similar to both 40° and 50° tilts was that stare mode coverage was confined to the central areas of the continents of North America, South America, Africa, and Asia (Figure 1); also, both covered a portion of Antarctica. Australia was only imaged at a tilt of 40°, and the extent of this coverage was a band across the northern central region of the continent (Figure 1).

Relative differences in extent of coverage between 40° and 50° tilts are observed in the latitudinal and longitudinal extents of coverage. At 40° tilt the extent of coverage was increased in latitude, but decreased in longitude relative to the extent of coverage at 50° tilt. The reasons for these differences in coverage are that the smaller 40° tilt allowed for the sensor to begin land coverage at a lower latitude (northern hemisphere, ascending orbit) and continue land coverage to a higher latitude, when switching between ocean and land tilt priorities (effect the same for southern hemisphere ascending orbits, just reversed); the difference in longitude coverage is the result of differing ground swath widths, the 40° tilt ground swath was narrower than the 50° tilt ground swath width. These differences in coverage were generally observed for the continents imaged by both tilts. Stare mode coverage of Australia was obtained only at 40° tilt which apparently was the result of MODIS-T being able to look at the continent at this tilt, between ocean priority tilts, which was not possible at the 50° tilt.

The simulations conducted indicate that the extent of land coverage, latitudinal and longitudinal, by MODIS-T in stare mode will be affected by the tilt angle. From the perspective of building a BRDF these simulations indicate regions from which data, at different tilt angles, may be acquired for the purpose of building a BRDF.

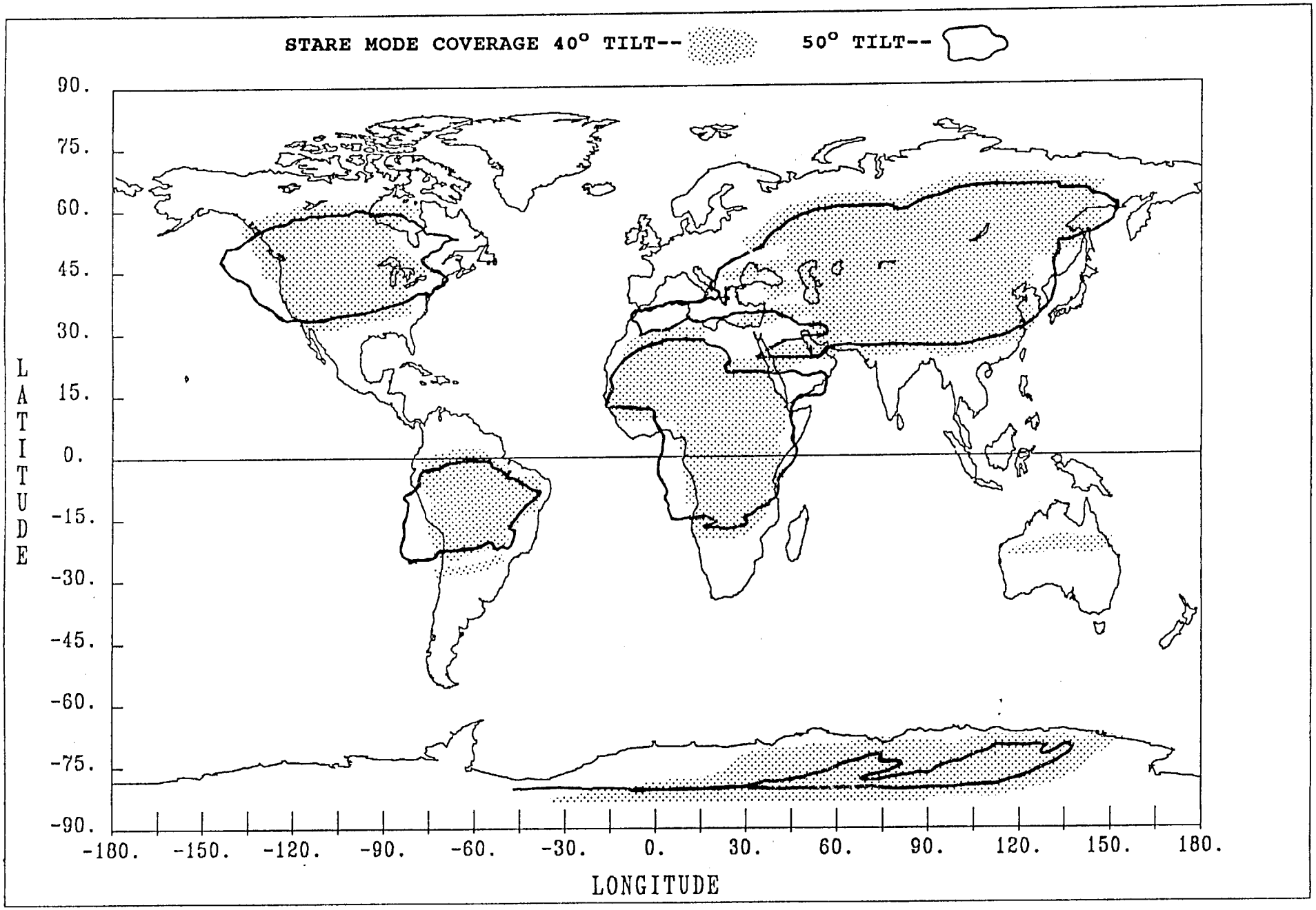

STARE MODE COVERAGE 40° TILT--
50° TILT--
90.
75.
60.
45.
30.
15.
0.
-15.
-30.
-45.
-60.
-75.
-90.
LATITUDE
-180.
-150.
-120.
-90.
-60.
-30.
0.
30.
60.
90.
120.
150.
180.
LONGITUDE

FIGURE 1

Comparison of Ocean Processing Estimates
Based on CZCS Code to Data Study Team's
Independent Estimates

This is a revision of a previous estimate of CPU requirements for MODIS. This revision takes into account that the Miami model for the CZCS was generated using only every 4th pixel. Here we correct for this to estimate MODIS processing.

CPU Requirements

According to Dr. Robert Evans, it required 20 minutes to process a 2-minute CZCS scene on a MicroVax II. This processing included atmospheric corrections and generation of water-leaving radiances, and production of pigment concentrations for every 4th pixel in a scan line. A 2-minute scene involved 970 scan lines (single detector), thus it required 1.237 seconds to process a single CZCS scan. Note that this estimate includes all levels of processing. From a series of computer timing tests using LINPACK (Dongarra, 1989), the speed of the MicroVax II is taken as 0.13 MFLOPS. Thus we derive 0.16 MFLOP/scan for CZCS processing.

Since about half of the processing time is spent on Level-3 algorithms in the CZCS, and Level-1 requires about 25% of the other half, the CZCS requires about 0.06 MFLOP/scan for Level-2 processing. Dividing by the number of pixels and bands, we arrive at 30.48 operations/band/pixel for the CZCS.

Evans recommended we scale these values to MODIS bands and wavelengths and multiply by 10 to obtain an estimate for MODIS processing requirements. Accordingly, we arrive at 295 MFLOP/scan for MODIS-T and 77 MFLOP/scan for MODIS-N. These estimates include cloud filters, so our estimates must account for clouds. We assume a 50% reduction in processing due to clouds. Results are shown in Table 2.

Table 2. Comparison of processing requirements for MODIS using the MODIS Data Study Team's (MDST) estimates and those derived from UMiami's CZCS processing for atmospheric correction and pigment concentration.

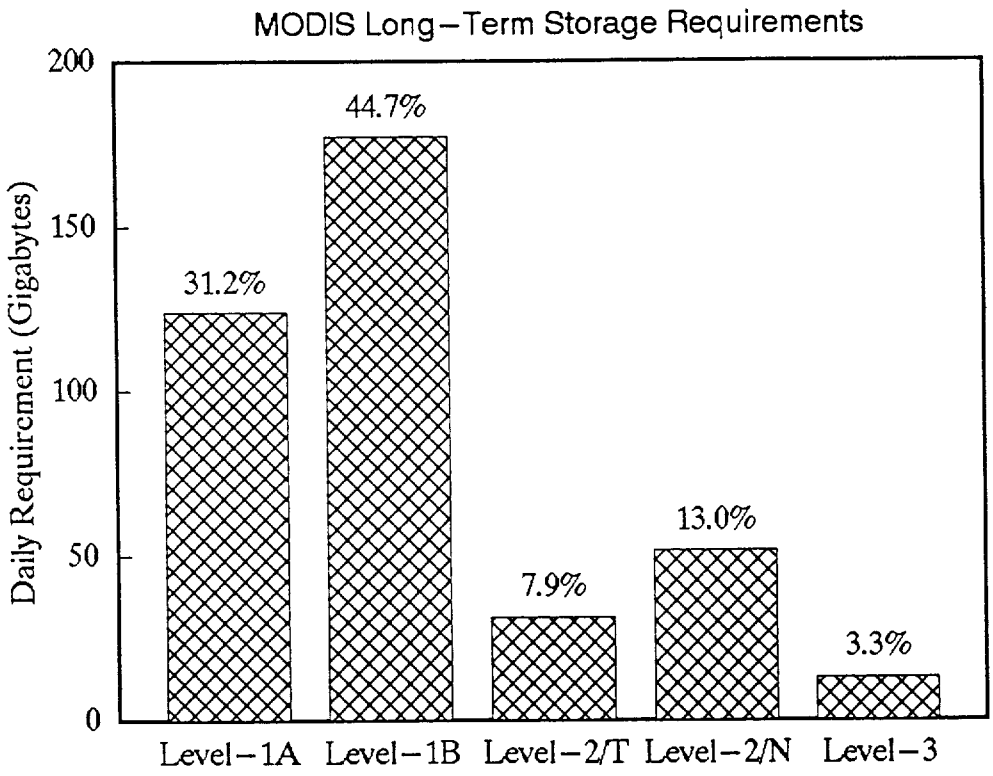
	MDST	Derived from CZCS	
MODIS-N	40	77	MFLOP/scan
MODIS-T	156	295	MFLOP/scan

The estimates based on the CZCS exceed MDST estimates by about a

factor of 2. MODIS ocean processing requires generation of new data products, for which algorithms have not been formalized, and a new pixel-by-pixel atmospheric correction procedure. Thus this difference is small considering the uncertainty involved. Therefore, we consider these estimates roughly in agreement.

Reference

Dongarra, J.J., 1989. Performance of various computers using standard linear equations software in a Fortran environment. Tech. Mem. 23, Argonne Nat. Lab.


MODIS Long–Term Storage Requirements
Daily Requirement (Gigabytes)
200
150
100
50
0
31.2%
44.7%
7.9%
13.0%
3.3%
Level–1A
Level–1B
Level–2/T
Level–2/N
Level–3

MODIS LONG-TERM ARCHIVE STORAGE REQUIREMENTS (GIGABYTES/DAY)

	Daily				Equivalent Daily		
			MODIS-T	MODIS-N			
Data Product	Level-1A	Level-1B	Level-2	Level-2	Level-3	Level-4	Total/day
Total	123.5	177.1	31.3	51.4	13.1		396.5
Navigation	0.07	22.66					22.7
Calibration	7.67						7.7
Engineering/Housekeeping	5.51	7.35					12.9
At-Satellite Radiances	110.29	147.06					257.3
Water-Leaving Radiances			10.14	5.42	6.27		21.8
Single Scattering Aerosol Radiances			8.23	3.61			11.8
Angstrom Exponents			10.14	5.42			15.6
Chlorophyll-A Concentrations (Case 1)			0.32	0.60	0.23		1.2
Chlorophyll-A Concentrations (Case 2)			0.03	0.06	0.23		0.3
Chlorophyll-A Fluorescence			0.32	0.60	0.23		1.2
CZCS Pigment Concentrations			0.32	0.60	0.23		1.2
Sea-Surface Temperature				1.51	0.23		1.7
Sea-Ice Cover				0.18	0.07		0.3
Attenuation at 490 nm			0.32	0.60	0.23		1.2
Detached Coccolith Concentration			0.10	0.18	0.23		0.5
Phycoerythrin Concentrations			0.32		0.23		0.5
Dissolved Organic Matter			0.32	0.60	0.23		1.2
Seston			0.32	0.60	0.23		1.2
Ocean Cal Data Sets							
Primary Production			0.32	0.60	0.23		1.2
Land-Leaving Radiances				19.68	0.01		19.7
DEM/DTM							
Vegetation Index				5.16	1.73		6.9
Land Surface Temperature				0.65	1.22		1.9
Thermal Anomalies				0.65	1.22		1.9
Snow Cover				0.32	0.0009		0.3
Land Cover Type					0.0001		0.0
Bidirectional Reflectance, BRDF					0.0068		0.0
Cloud Mask			0.16	1.08			1.2
Cloud Fraction					0.0075		0.0
Cloud Effective Emissivity				0.09	0.0005		0.1
Cloud-Top Temperature and Pressure				0.34	0.0010		0.3
Cloud Optical Thickness (0.66 μm)				0.09	0.0003		0.1
Cloud Particle Effective Radius				0.09	0.0003		0.1
Cloud Particle Thermodynamic Phase				0.04	0.0003		0.0
Aerosol Optical Depth (0.41 to 2.13 μm)					0.0010		0.0
Aerosol Size Distribution					0.0010		0.0
Aerosol Mass Loading					0.0010		0.0
Atmospheric Stability				0.17	0.0021		0.2
Total Precipitable Water				2.32	0.0031		2.3
Total Ozone				0.17	0.0010		0.2
Browse							
Metadata							

Product		Resolution		Gbytes Storage			
		Spatial	Temporal	Day	Week	Month	Comments
Vegetation Index**	Level 2 Level 3	214m*214m 214m*214m 10 km 10 km	Daily Weekly Weekly Monthly	5.1	 10.3 0.02	 0.02	Level 2--2 bytes per product Level 3--4 bytes per product $5.1*10^6$(cells)*4(bytes)/10^9
Land Cover Type**	Level 3	10 km	Quarterly			0.02	Produced 4 times a year
Snow Cover**	Level 2 Level 3	856 m 10 km	Daily Weekly	0.3	 0.02		No 50% Reduction for Snow Extent
Surface Temperature**	Level 2 Level 3	856m*856m 1 km	Daily Weekly	0.6		 1.2	Day and Night Products 2*($1.5*10^8$(cells)*8(bytes)
Thermal Anomalies**	Level 2	856m	Daily	0.3			May be a Listing of Anomalies
Land-Leaving Radiances Computed for Reflective Bands	Level 2 Level 3	214m 428m 856m 1 km 10 km 10 km	Daily Daily Daily Weekly Weekly Monthly	10.3 6.4 2.9	 32.6 0.3	 0.32	2 Bands 5 Bands 9 Bands
Subtotals				26.0	44.5	0.4	70.9
Surface Spectral Albedo							
Cloud Mask							
BRDF							

**Identified as at-launch

Storage Considerations for MODIS Ocean Color Data. Level 2

Processing of MODIS ocean color data products requires and produces several data sets and look-up tables. It is important to estimate the size of these data sets and tables in order to estimate storage requirements for MODIS. These data sets will be divided into three categories: 1) external data sets and look-up tables, 2) ancillary data, and 3) output data sets.

External data sets and look-up tables (e.g., extraterrestrial solar irradiance, ozone absorption coefficients) are generated prior to launch and remain unchanged in processing. Ancillary data (e.g., pressure, wind speeds, and ozone) are data required to produce MODIS ocean color products and may be obtained from sources external to MODIS. Output data sets are the products themselves.

More external data sets and look-up tables may be required than listed here as the algorithms become more refined. This list then serves as a rough estimate of the storage requirements for MODIS ocean color processing, representing our present knowledge of the algorithms.

For all estimates we assume 4-byte words.

Symbols Table

	MODIS-N	MODIS-T
I = number of pixels along scan	1582	1007
J = number of pixels along track	8	30
IA = number of anchor points along scan	94	80
JA = number of anchor points along track	2	5
L = number of wavelengths	9	32
N = number of scans per day	8.47×10^4	1.90×10^4
P = number of pixels per day (I*J*N)	1.07×10^9	5.75×10^8

A. External Data Sets -- these do not change	Dimensions
Mean extraterrestrial irradiance	L
Ozone absorption coefficients	L
Rayleigh optical thickness, standard	L
Fourier coefficients look-up table	40,39,L,3
Anchor point array counter	IA
Anchor point array counter	JA
Lambda	L
Chlorophyll (Case-2 Chlorophyll Algorithm)	13,15
Gelbstoff (Case 2 Chlorophyll)	13,15

MODIS-N	0.2 Megabytes
MODIS-T	0.6 Megabytes

B. Ancillary Data Sets	Dimensions
Pressure	360,180
Wind speeds	360,180
Ozone	360,180

Assuming data are obtained at 1° x 1° horizontal resolution, and that pressure and winds speeds are obtained 4 times per day from the NMC, and the ozone data is obtained once per day from another sensor,

MODIS N&T 1.3 Mb/day

C. Output Data Sets (units are Gigabytes/day)

Symbols:
O = percent of ocean coverage = 0.7
D = percent of day coverage = 0.4

	Notes	MODIS-N	MODIS-T
Normalized water-leaving radiance 4 * P * O * D * L	All L	10.8	20.6
Single-scattering aerosol radiance 4 * P * O * D * (L > 500 nm)	L>500nm	7.2	16.7
Angstrom exponents 4 * P * O * D * L	All L	10.8	20.6
Chlorophyll a Conc. (Case 1) 4 * P * O * D		1.2	0.6
Chlorophyll a Conc. (Case 2) 4 * P * O * D * 0.1	10% of ocean	0.1	0.1
Chlorophyll a Fluorescence 4 * P * O * D		1.2	0.6
CZCS Pigment Concentrations 4 * P * O * D		1.2	0.6
Sea Surface Temperature 4 * P * O	Day and night	3.0	---
Attenuation at 490 nm 4 * P * O * D		1.2	0.6
Detached Coccolith Conc. 4 * P * O * D * 0.3	30% of ocean	0.4	0.2

Dissolved Organic Matter 4 * P * O * D		1.2	0.6
Sea Ice 4 * P * O * D * 0.3	High latitudes only	0.4	---
Phycoerythrin Concentrations 4 * P * O * D		1.2	0.6
Total Seston Concentrations 4 * P * O * D		1.2	0.6
Calibration Data Sets	Sporadic in time and space		
Primary Production 4 * P * O * D		1.2	0.6

TOTALS

MODIS-N	42.3 Gigabytes/day
MODIS-T	63.2 Gigabytes/day

E MATE OF MODIS PROCESSING REQUIREMENTS

General information:	maximum pix/sec	channels	daytime tot/sec	nighttime tot/sec	Gpixels /day
MODIS-N pixels/sec/lambda (visible 1 km):	12408	12	148894	0	6.43
MODIS-N pixels/sec/lambda (thermal 1 km):	12408	17	210933	210933	18.22
MODIS-N pixels/sec/lambda (0.5 km):	49631	5	248157	0	10.72
MODIS-N pixels/sec/lambda (0.25 km.):	198525	2	397051	0	17.15
MODIS-T pixels/sec/lambda (1.1 km):	7208	32	230656	0	9.96
			1235691	210933	62.49

Percent computer usage:	70.0	Based on Sharts estimate
Percent downtime:	10.0	Based on NCAR operations
Percent browse overhead:	0.1	SS, p. 99; assumes proc. & data loa
Percent metadata overhead:	0.2	SS, p. 99; assumes proc. & data loa
Percent I/O overhead:	20.0	Based upon System Specs.; p. 75.
Number of reprocessings:	2	Based on EosDIS requirements
Calculated overhead above Level 2:	3.77	Calculated from above assumptions
Assumed day/night duty cycle:	0.5	Visible channels on during day only
Assumed fractional cloud cover:	0.5	Based upon climatology.
Assumed fractional land cover:	0.3	Using known geography.
Assumed fractional ocean cover:	0.7	Using known geography.

	Mflops:	Ops/pix:	Pix/sec:	no. of products	no. of inputs	Storage (Gp/day)
BASIC LEVEL 1A PROCESSING:						
MODIS-N (visible 1 km):	1.12	15	6204	12	12	6.432
MODIS-N (thermal 1 km):	3.16	15	12408	17	17	18.225
MODIS-N (0.5 km):	1.86	15	24816	5	5	10.720
MODIS-N (0.25 km):	2.98	15	99263	2	2	17.153
' `IS-T (1.1 km):	1.73	15	3604	32	32	9.964
B. C LEVEL 1B PROCESSING:						
MODIS-N (visible 1 km):	2.59	35	6204	12	12	6.432
MODIS-N (thermal 1 km):	5.06	24	12408	17	17	18.225
MODIS-N (0.5 km):	3.72	30	24816	5	5	10.720
MODIS-N (0.25 km):	8.34	42	99263	2	2	17.153
MODIS-T (1.1 km):	2.83	25	3604	32	32	9.964
LAND LEVEL 2 PROCESSING:						
Land leaving radiances (8):	3.72	500	931	8	9	0.643
NDVI(1 km):	0.00	0	931	1	2	0.080
NDVI(0.5 km):	0.00	0	3722	1	2	0.322
NDVI(0.25 km):	0.60	20	29779	1	2	2.573
Land surface temperature (LST):	2.61	1400	1861	1	3	0.161
Land cover type:	0.66	44	14889	1	2	1.286
Weekly global snowcover maps:	0.04	44	931	1	3	0.080
Thermal anomalies and fires:	1.29	52	12408	2	4	2.144
Surface spectral albedo maps (8):	0.00	0	931	8	9	0.643
OCEAN LEVEL 2 PROCESSING:						
Water leaving radiances (32):	10.94	126	2171	40	40	7.504
Single scattering aerosol radiance:	0.00	0	2171	1	1	0.188
Angstrom coefficient:	0.00	0	2171	1	3	0.188
Chlorophyll-a conc.(case 1 waters):	0.08	39	2171	1	2	0.188
Chlorophyll-a conc.(case 2 waters):	0.01	130	109	1	2	0.009
Chlorophyll fluorescence:	0.22	100	2171	1	3	0.188
CZCS pigment concentrations:	0.07	34	2171	1	2	0.188
Sea surface temperature:	3.04	700	4343	1	3	0.375
Detached coccolith concentrations:	0.09	40	2171	1	4	0.188
Phycoerythrin pigment concentration	0.11	52	2171	1	2	0.188
Dissolved organic material conc.:	0.08	39	2171	1	2	0.188
Attenuation in oceans at 490 nm:	0.22	100	2171	1	1	0.188
Total seston concentrations:	0.08	39	2171	1	2	0.188
' nary productivity (case 1):	0.09	41	2171	1	4	0.188
. situ validation observations:	0.22	100	2171	1	1	0.188

P SPHERIC LEVEL 2 PROCESSING:						
Cloud opt. depth, drop size & phase	12.66	51000	248	3	8	0.064
Cloud properties: Emis., T, and P:	0.74	3000	248	3	8	0.064
Cloud flags:	6.20	500	12408	1	4	1.072
Aerosol optical depth (8):	0.06	63	124	8	8	0.086
Aerosol size distribution (8):	28.34	28549	124	8	12	0.086
Total column ozone:	0.00	100	5	1	18	0.000
Total precipitable water(2 algs.):	0.00	100	5	2	18	0.001
Lifted index:	0.00	100	5	1	18	0.000
Layer mean temperatures:	4.22	850000	5	1	18	0.000
Layer mean moisture:	4.22	850000	5	1	18	0.000
Total number of Level 2 products out, in, and stored(Gpix/day):				243	374	144.44

LEVEL 2 TO 3 PROCESSING:				# rect.	
LAND PRODUCTS:					
MODIS-N (visible 1 km):	6.58	372	931	19	SS, p. 75.
MODIS-N (thermal 1 km):	2.08	372	1861	3	SS, p. 75.
MODIS-N (0.5 km):	2.77	372	7445	1	SS, p. 75.
MODIS-N (0.25 km):	11.08	372	29779	1	SS, p. 75.
OCEAN PRODUCTS:					
MODIS-T (1.1 km):	7.04	372	1261	15	SS, p. 75; WLR not
ATMOSPHERIC PRODUCTS:					
MODIS-N (visible 1 km):	1.85	372	248	20	SS, p. 75.
MODIS-N (thermal 1 km):	2.22	372	496	12	SS, p. 75.
MODIS-N (0.5 km):	0.00	372	12408	0	SS, p. 75.
MODIS-N (0.25 km):	0.00	372	49631	0	SS, p. 75.

	Mflops	With % use Mflops	Cum. sum Mflops	Data Volume Gpix/day	Cum. sum Volume	Data Volume GB/day
L 1 1A processing (w/o DTM):	10.85	15.50	15.50	62.49	62.49	124.99
Level 1A processing (DTM overhead):	4.96	7.09	22.59	11.07	73.56	22.13
Level 1B processing:	22.54	32.20	54.79	62.49	136.06	124.99
Land Level 2 processing:	8.91	12.73	67.52	7.93	143.99	31.73
Ocean Level 2 processing:	15.27	21.81	89.33	10.14	154.13	40.56
Atmospheric level 2 processing:	56.44	80.64	169.96	1.37	155.50	5.50
Level 2 to level 3 processing:	33.60	48.00	217.96	7.80	163.31	31.22
Level 3 to level 4 processing:	0	0.00	217.96	0.00	163.31	0.00
Browse processing:	0.15	0.22		0.16		0.33
Metadata processing:	0.31	0.44		0.33		0.65
I/O overhead:	30.61	43.72				
Downtime overhead:	18.36	26.23				
Twice reprocessing:	404.01	577.15				
Storage required (Gpix/day and GB/day):				163.80		382.10

Grand total of processing (MFLOPS):	865.73	822.03	
Grand total of processing (GFLOPS):	0.87	0.82	
Grand total (UARS analog, method 1; GFLOPS):		17.36	Assumes UARS CDHF=6.4 Mflop
Grand total (UARS analog, method 2; GFLOPS):		17.36	Assumes MODIS has 24000 ops

Grand total as function of N ops/pixel (GFLOPS):		N ops/pix
	1.45	2000
	2.89	4000
	4.34	6000
	5.79	8000

ARY ESTIMATE OF MODIS CDHF REQUIREMENTS:

	N	MFLOPS /var. with no overhead	Total	Total + overhead
Level 0 to 1A:	66	0.24	15.81	29.91
Level 1A to 1B:	66	0.34	22.54	42.63
Land variables:	24	0.37	8.91	16.85
Ocean variables:	54	0.28	15.27	28.87
Atmospheric vars:	29	1.95	56.44	106.76
Level 3:			33.60	63.55
Total (MFLOPS):			152.57	288.58
Re-processing (MFLOPS):				577.15
Grand total (GFLOPS):				0.87

LEVEL-2 PRODUCT VOLUMES
ATMOSPHERE

This is an analysis of the daily data volume that will be generated in producing the Level-2 atmosphere (cloud and clear-sky) data products. This discussion of the products is arranged as in the Level-2 to Level-3 processing discussion and common symbols are used.

Cloud Optical Depth, Effective Particle Radius

All atmospheric products will be generated from MODIS-N data only. This implies about 12,000 FOV/sec. These products will be generated at 5 km spacing which is approximately 1 in 25 pixels. A factor of 0.4 (0.5) is used for daytime. It is assumed that on average clouds are present 50% of the time (though the product may be "sparse"). The Level-2 data rate will be

$$12{,}000*0.4*0.5/25 = 97 \text{ L-2 data/sec.}$$

It is assumed that there will be 8 Bytes per data value. This corresponds to a R*4 number as the value and a second R*4 value as an error. This probably corresponds to an overestimate of the data volume.

Cloud Water Thermodynamic Phase

This product is produced in common with cloud optical depth so the rate is 97 L-2 data/sec. This is a simple product so we have assumed 1 (I*2) Byte per data product.

Cloud Effective Emissivity, Top Temperature, Top Height, Atmospheric Stability, Total Precipitable Water, Total Ozone Content

These products will each be produced with 50% (100%) coverage, either clear-sky or cloudy as appropriate. The algorithm will work both day and night so the 0.4 factor is not used. The L-2 data rate will be

$$12.000*0.5/25 = 243 \text{ L-2 data/sec.}$$

It is again assumed that 8 Bytes are used per data point.

Aerosol Optical Depth, Size Distribution, and Mass Loading

These products are assumed to be generated at Level-3 so there is no Level-2 data to be stored.

Total

Based on selected assumptions above, the Level-2 data volume is:

$$97*2*8 + 97*1 + 243*6*8 = 13{,}313 \text{ B/sec}, \underline{1.2 \text{ GB/day}}.$$

Ancillary Data Volume

The above number indicates the volume of the Level-2 data products. There will be ancillary data required in generating these. These data are assumed to be archived with the Level-2 products and hence will increase the daily data volume.

The products produced in cloud effective emissivity, top temperature, top height, atmospheric stability, total precipitable water, total ozone content will require atmospheric profiles as ancillary data. While the source of this data is not fully defined, it is possible to estimate the data volume. Assume a horizontal resolution of R (50km) with N (20) levels at 8B/level and profiles generated T (4) times per day. These profiles will cover the entire Earth which has area A = $5.1X10^8$ km^2. The total volume is

$$A*(1/R^2)*N*T*8B \qquad (131MB/day).$$

Additional Processing Storage

There will be additional information required to generate the products that need not be archived. In particular, the algorithm of Dr. King uses a 15MB Look-up-Table. This table will not change so it need not be archived with each Level-2 data set. These data must be accessible during processing.

Storage Requirements
for
Level-3 Products

The following discussion contains an estimate of the storage required for the Level-3 MODIS core data products. This estimate has been generated in terms of storage required per day. For those products that are generated over weekly or monthly periods, the storage requirement has been expressed as the equivalent daily requirement. i.e., the daily storage of a weekly product is 1/7 of the weekly volume.

The processing scheme which we have developed will require buffer storage for all of the Level-3 products. This means that the daily, weekly, and monthly products will all be accumulated simultaneously. The size of the buffer is also estimated in the following discussion.

The buffer storage can be either online or RAM. The processing will be faster if all of the arrays can be held in memory. If the arrays are stored on fast disks, the processing on the fly will be somewhat slower. The issue of RAM versus on-line storage needs futher study. It is assumed that the Level-3 products are generated directly from the Level-2 data and that no additional information is required. i.e., no additional storage.

The following discussion is modelled after the presentation of Level-3 processing. The products are presented in the same order and the same symbols are used.

Atmospheric Products

The Level-3 atmospheric products will be generated with 1 degree resolution. (The exception is aerosol products which will be generated at Level-3 with 1/2 degree resolution.) All products will be generated with daily weekly and monthly time coverage. There are $4.2X10^4$ grid cells to cover the globe with 1 degree resolution (assuming equal area cells). The weekly and monthly product increase the required storage by a factor of (1 + 1/7 + 1/30) = 1.1762. Storing all products implies the equivalent of $4.94x10^4$ L-3 cells per day.

A1 - Cloud Optical Depth, Effective Particle Radius

The Level-3 product is expected to take the form of histograms and associated statistics. It is assumed that there will be 25 bins with 2 Bytes per bin for each histogram plus 2 statistics, e.g., mean and standard deviation, at 4 Bytes per statistic. This implies 25*2 + 2*4 = 58 Bytes per L-3 cell.

A2 - Cloud Water Thermodynamic Phase

This is a simple product that will take the form of fraction clear, ice, and water. This can be done with 6 Bytes per L-3 cell.

A3 - Cloud Effective Emissivity, Top Temperature, Top Height, Atmospheric Stability, Total Precipitable Water, Total Ozone Content

These products will have the same form and size as A1 with the exception that separate day and night products can be expected, i.e., this is the equivalent of 12 products.

A4 - Cloud Fractional Area

This product is assumed to be a histogram with 10 bins, clear and nine cloud types. With 2 Bytes per bin and 8 Bytes for 2 statistics, this product require 28 Bytes per L-3 cell.

A5 - Aerosol Optical Depth, Aerosol Size Distribution

It is assumed that these products will require 8 Bytes/cell. With the resolution of 1/2 degree there will be four times as many Level-3 cells.

Atmospheric Total

$[2*58 + 6 + 6*2*58 + 28 + 2*4*81*4.94X10^4 = \underline{0.04\ GB/day}$.

Ocean

The Level-3 ocean products will have $5.1X10^7$ 1 km cells in the daily product, $9.5X10^6$ 4 km cells in the weekly product, and $8.9X10^5$ 20 km cells in the monthly product. This is equivalent to $5.24X10^7$ cells per day.

O1 - Chlorophyll, Chlorophyll Fluorescence, Pigment Concentration, Attenuation @490, Detached Coccoliths, Dissolved Organic Matter, Single Scattering Aerosol Radiance, Angstrom Exponents, Total Sestun (10 total).

It is expected that all of these product will take the form of a data value and a single quality statistic, e.g., mean and

standard deviation which can be done in 8 Bytes. Carrying a second statistic, e.g., sum on squares, will increase the ocean storage requirement by 50%.

O2 - Sea Surface Temperature, Sea Ice

These Level-3 products are expected to have the same Level-3 volume as O1 (overestimate for ice).

O3 - Water Leaving Radiance

This is again similar to O1 except that there are 24 products, 9 MODIS-N bands and 15 MODIS-T bands.

O4 - Primary Production

Assume for sizing purposes that this Level-3 product will be of the same volume as O1. This should be an overestimate.

Ocean Total - equivalent to 37 products

37*5.04X10^{7}*8 = <u>15.5 GB/day.</u>

Land

It is assumed that all of the Level-3 land products will be generated with 10 km resolution. This implies that there are 5.1X10^{6} Level-3 grid cells.

L1 - Land Leaving Radiance, Surface Reflectance

There will be four products generated daily, weekly, and monthly. The three compositing periods are equivalent to 6.0X10^{6} per day. It is assumed that the Level-3 product will take the form of an average and standard deviation which requires 8 Bytes per cell.

L2 - NDVI

The NDVI Level-3 product will be generated only weekly and monthly which is equivalent to 9.0X10^{5} cells per day. The product is expected to take the form of histograms as in A1 which requires approximately 56 Bytes per Level-3 cell.

L3 - Surface Temperatures

Separate day and night products will be generated each of which is expected to be the equivalent of A1.

L4 - Snow Cover

A single product will be generated weekly and monthly that covers only 50% of the land surface. Assume 8 Bytes per Level-3 cell.

L5 - Land Cover

This product will be genrated perhaps 2-4 times per year which will require insignificant storage.

L6 - Thermal Anomalies

This product could be a list of locations. Negligible Level-3 storage is required.

Land Total

$6*6.0X10^6*8 + [0.5*8 + 1.3*58]*9.0X10^5 = \underline{0.34\ GB/day}$.

Total Total

$0.04 + 15.5 + 0.34 = \underline{15.9\ GB/day}$.

This number represents the average volume of Level-3 data.

Buffer Storage

There will be daily, weekly, and monthly products generated which will require that the Level-2 data be simultaneously com-posited into more than one Level-3 product. There will be a buffer storage which will hold the equivalent of one copy of each Level-3 product for each compositing period. This buffer will be larger than the average daily volume.

For the atmospheric products, there will be 3 Level-3 work-ing arrays to accomodate the daily, weekly, and monthly products. The buffer storage will be three times the average daily volume.

For the ocean products, the 1 km, 4 km, and 20 km Level-3 grids will be used simultaneously for accumulating the Level-2

data. This implies that the buffer must be 20% larger than the average daily volume.

For the land products, there will be the equivalent of three copies of products L1 and L3 and 2 copies of L2 and L4. The required buffer storage is:

$$5.1 \times 10^6 * [\ 6*8*3 + (0.5*8 + 58)*2\ ] = 1.37\ GB.$$

The total requirement for the buffer storage is then

$$3*0.08 + 1.2*15.5 + 1.37 = \underline{20.0\ GB}.$$

This figure represents the volume of storage required to accumulate all of the Level-3 products on the fly, i.e., as the Level-2 data is processed.